Repeatability of Brain Tissue Volume Quantification using Magnetic Resonance Images

Juan D. Gispert , Santiago Reig , Javier Pascau , Juan J. Vaquero , Manuel Desco
Medicina y Cirugía Experimental. Hospital General Universitario Gregorio Marañón. Madrid, Spain.

INTRODUCTION

The conventional way to characterize MR tissue measurements has been to assess accuracy and precision (or repeatability) (i.e. systematic and random errors). Sources of error (contributing to both inaccuracy and imprecision) arise both in the data collection procedure and in the image analysis procedure. Two main sources of systematic error in data acquisition are B1 non-uniformity and partial volume effects. Precision may have a large biological component because of the significant intra-subject biological variation. Besides, patient positioning and movement contribute to random errors (Tofts, 2003). Accuracy of MR quantification methods has received greater attention than precision. However, systematic errors do not mask differences in group comparisons whilst imprecision decreases the statistical power of the statistical test. Early works that measured the reproducibility of MRI analysis procedures have little practical value, since patient positioning was not considered and can be a major source of variation (Gawne-Cain et al., 1996; Tofts, 1998).

The aim of this work is to study the repeatability of brain tissue volume quantification achieved by different MRI segmentation methods. We have quantified the variance components associated to different sources, considering both data acquisition variability (including biological, scanner and positioning variability) and image post-processing variability (introduced by intensity inhomogeneity and segmentation algorithms). We have also measured the reproducibility of eight different MRI tissue segmentation algorithms under different acquisition and post-processing conditions by calculating the standard deviation of the repeated measurements (absolute variability, in cm3) and the coefficient of variation (CV) (relative variability, in percentage).

MATERIAL AND METHODS

Two experiments were conducted using an MR dataset consisting in a total of 24 MR images of 4 different subjects, acquired in 2 different MR scanners of different static field (0.5 and 1.5 Tesla) and repeating the acquisition in each scanner 3 times. All these images were then corrected for intensity inhomogeneities with the N3 algorithm. Both the corrected and uncorrected images were segmented by using eight different MRI segmentation algorithms, selected on the basis of being representative of the use of partial volume modeling (Santago and Gage, 1995; Laidlaw et al., 1998; Grabowski et al., 2000; Ruan et al., 2000) or the use of statistical templates (Ashburner and Friston, 1997; Van Leemput et al., 1999). Images were also segmented by a baseline reference algorithm which does not implement any partial volume modeling nor uses statistical templates (Wells et al., 1996).

RESULTS

Figures 1 to 3 show the percentage of variance explained by the 5 sources of variability considered and Table 1 the reproducibility of the 8 segmentation algorithms under the different measurement conditions.

CONCLUSIONS

Our results indicate that the explicit modeling of partial volume effects improves the MRI segmentation repeatability. The inclusion of spatial information by using anatomical templates and spatial normalization techniques enables a greater improvement in the repeatability, although it is very sensitive to eventual registration errors.

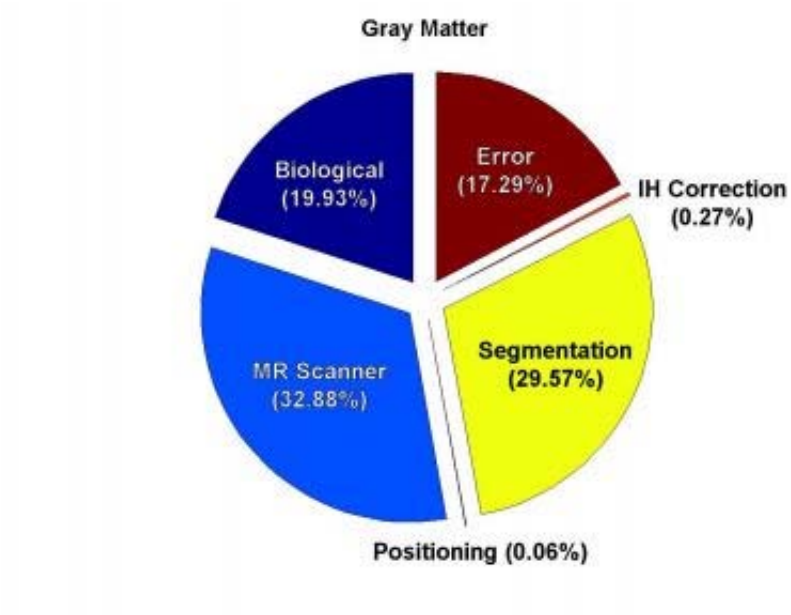

Figure 1: Percentage of variance explained in Gray Matter quantification by the different factors: Subject (Biological variability), MR scanner, Positioning (nested in MR scanner), Intensity inHomogeneity Correction and Segmentation Algorithm

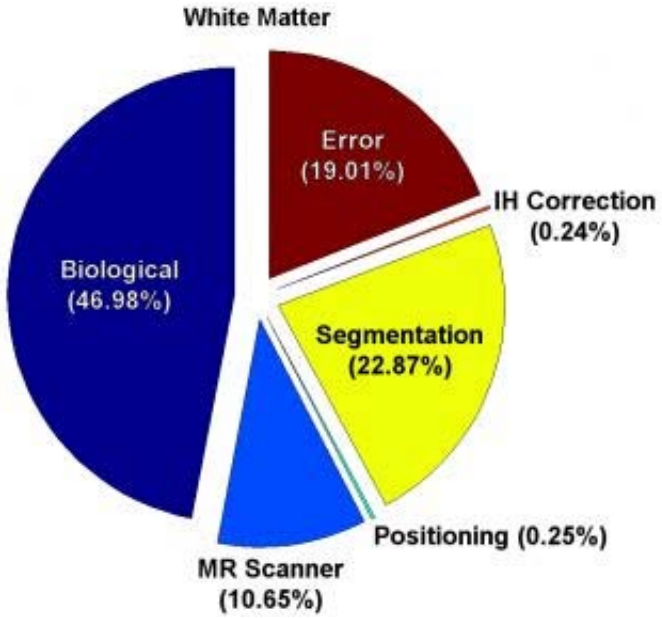

Figure 2: Percentage of variance explained in White Matter quantification by the different factors: Subject (Biological variability), MR scanner, Positioning (nested in MR scanner), Intensity inHomogeneity Correction and Segmentation Algorithm

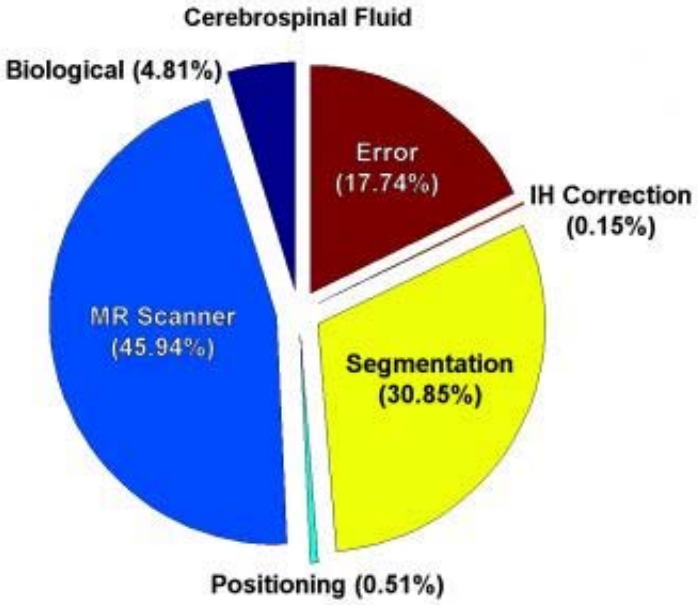

Figure 3: Percentage of variance explained in Cerebrospinal Fluid quantification by the different factors: Subject (Biological variability), MR scanner, Positioning (nested in MR scanner), Intensity Inhomogeneity Correction and Segmentation Algorithm

MR Scanner	0.5 T				1.5 T			
IH Correction	N3		None		N3		None	
	Abs. (cm^3)	Rel. (%)	Abs. (cm^3)	Rel. (%)	Abs. (cm^3)	Rel. (%)	Abs. (cm^3)	Rel. (%)
Gray Matter								
Wells	38.77	4.47	36.85	4.65	88.62	10.08	96.69	9.40
Santago	20.45	2.10	22.77	2.09	22.13	2.14	48.66	3.77
Laidlaw	15.35	1.46	19.57	1.90	27.00	2.53	31.88	3.00
Ruan	18.26	1.73	38.36	3.38	19.96	1.87	34.72	3.57
Grabowski	13.25	1.38	20.71	2.06	51.24	4.37	58.31	4.95
SPM	7.21	0.92	9.16	0.87	6.16	0.68	3.88	0.42
EMS	8.00	1.18	8.13	1.17	68.47	9.74	69.27	9.76
EMS+MRF	11.63	1.49	10.23	1.33	58.30	8.54	56.16	8.27
White Matter								
Wells	13.45	2.72	11.74	2.31	30.30	7.03	38.45	7.29
Santago	16.68	3.36	13.60	2.65	19.55	4.92	39.52	7.53
Laidlaw	14.80	3.28	15.58	3.63	19.14	4.79	26.19	6.67
Ruan	21.81	2.98	29.24	5.02	15.73	3.07	27.35	5.75
Grabowski	11.96	2.81	15.83	3.40	23.12	5.61	28.67	7.19
SPM	5.16	0.87	4.90	0.81	4.07	0.74	3.84	0.69
EMS	18.41	2.21	18.76	2.25	120.44	14.27	120.55	14.28
EMS+MRF	7.42	0.93	8.36	1.08	70.15	8.04	71.95	8.26
Cerebrospinal Fluid								
Wells	26.23	5.49	29.54	6.63	61.99	23.91	62.25	24.11
Santago	11.80	3.55	14.11	3.59	3.70	2.03	10.24	4.66
Laidlaw	9.38	3.24	8.42	3.12	9.98	5.77	8.33	5.32
Ruan	11.08	3.13	13.62	3.53	5.74	2.82	13.28	5.03
Grabowski	10.45	2.69	10.54	2.73	34.69	9.94	37.28	11.33
SPM	5.03	1.27	6.60	1.71	3.54	1.19	3.12	1.26
EMS	12.52	10.97	12.60	11.20	57.29	58.35	55.45	57.99
EMS+MRF	15.67	9.68	15.02	9.47	67.23	43.04	66.02	42.83

Table 1: Mean values of the standard deviation (Abs., in cm3) and the coefficient of variation (Rel., in %) of the tissue volumes estimated using 0.5 T and 1.5 T MR scans and with and without intensity inhomogeneity correction (N3, None).